FERMILAB-Proposal-0729

A PROPOSAL TO STUDY

CHARM AND MULTIPARTICLE PRODUCTION IN 1 TeV PROTON-EMULSION COLLISIONS

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BEAM : 1 TeV protons

FLUX : $\sim 5 \times 10^4$ protons / cm^2

DETECTOR : Emulsion stack of 60 K5 pellicles each of the size 8 cm X 8 cm X 0.06 cm.

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15 pgs.

I. Introduction

Since the discovery of the J/ψ in 1974 and its interpretation as a hidden $c\bar{c}$ state a great deal of effort has gone into determining the properties of charm particles and their production and decay characteristics. The motivations for studying charm production characteristics in hadronic interactions are two-fold; firstly to obtain information on the production mechanism and to see if QCD can explain it, and secondly to obtain information on the structure of the colliding hadrons themselves, for example does a hadron contain a long lived $c\bar{c}$ component. Such questions can be answered only if one has relatively accurate determination of charm production cross-sections at various energies and with different beams.

The charm quark being heavy, significant open charm production starts only at centre of mass energies $\sim$ 15-20 GeV ($P_{lab} \sim$ 150 GeV). The maximum energy of the present fixed target machines being $\sim$ 400 GeV ($\sqrt{s} \sim 27$) only a very small range of $\sqrt{s}$ is available for study of open charm production at such machines. The CERN ISR has provided results on open charm at $\sqrt{s} \simeq 60$ GeV. At present, therefore, one has results on open charm production at only two well separated energy regions ($\sqrt{s} \simeq 25$ and 60 GeV). Thus, it is very important that an experimental study of charm production characteristics be made at an intermediate energy (e.g. $\sqrt{s}$ = 40–45 GeV) to provide a sharper test to the various models. With the advent of the Tevatron fixed target facility at Fermilab precisely such an energy will become available for such a study. We therefore propose to carry out a determination of the charm production cross-section using 1 TeV proton-emulsion interactions.

Emulsion experiments have played an important role in recent years in the understanding of hadron-nucleus collisions. The most striking observation is that the produced hadrons interact only weakly inside the nucleus. Because of the finite size of the nucleus, it acts as a kind of detector with a high time resolution since the characteristic time for the emission of hadrons is longer than the passage time through the nucleus. A variety of different models have been proposed to understand the features of hadron-nucleus collisions with the hope of ultimately shedding light on hadron- hadron interactions. An interesting new development is to understand hadron-nucleus collisions on the basis of quark model and its color-neutralization variant [1, 2]. However the situation is still not clear [3] (see also Aliev et al.). An important reason for this is that the available experimental data extends only to 400 GeV/c while predictions of some of the models differ only at much higher energies. It is therefore important to extend the experimental data to higher energies. We propose to study p-nucleus collisions at 1000 GeV using nuclear emulsions.

2. Charm Production

As mentioned above charm production data exists at $\sqrt{s} \sim 20$–27 GeV (from SPS/FNAL experiments) and at $\sqrt{s} \sim 60$ GeV (from ISR experiments). Whereas the ISR results [4] indicate a total charm production cross-section ~ 1 mb which includes inclusive Λ_c^+ cross-section of $\sim 250\ \mu$b, the situation at SPS/FNAL energies is still rather confused. Beam dump experiments [5] assuming central $D/\bar{D}$ production as the main source of prompt leptons deduce charm production cross-sections in the range of 15–20 μb/nucleon. On the other hand non-beam dump experiments [6] indicate inclusive Λ_c^+ cross-sections of $\sim$ 70–100 μb/nucleon. Recently the CDHS (CERN beam dump) group has reanalysed its data assuming that prompt neutrinos are due to associated $\Lambda_c^+\ \bar{D}$ production [7]. On this hypothesis they obtain a value of $87 \pm 22\ \mu$b/ nucleon for the inclusive Λ_c^+ cross-section. However, to fit the energy distribution of prompt neutrinos they used x dependences for Λ_c^+ and $\bar{D}$ of the form $(1-|x|)^3$ and $(1-|x|)^5$ respectively which are not in agreement with the x distributions determined at the ISR — $(1-|x|)$ for Λ_c^+ and $(1-|x|)^3$ for $D/\bar{D}$. It has recently been pointed out [8] that this discrepancy in the x dependences is due to wrong decay modes for Λ_c^+ and $D/\bar{D}$ being used by the CDHS group (they had used all three body modes $\Lambda_c^+ \to \Lambda e^+ \nu$, $D \to Ke\nu\ /K^* e\nu$). Using more realistic decay modes it is shown that all the beam dump data can be understood on the basis of simple quark counting rules [9] which indicate that in proton fragmention the exponent n of the x-dependence $(1-|x|)^n$ has the value of 1 for Λ_c^+, 3 for $\bar{D}$ associated with Λ_c^+ and 7 for associated $D/\bar{D}$ production. The charm production cross-sections obtained under this hypothesis range from 30–50 μb/nucleon.

In conclusion a reasonable estimate for inclusive Λ_c^+ cross-section in P-A interactions at SPS/FNAL energies is $\sim$50 μb/nucleon, and the charged $D^{\pm}$ cross-sections is also of the same order.

2.1 Estimate of charm signal at 1 TeV

The value of $\sigma\Lambda_c^+$ and $\sigma D^{\pm}$ being $\sim$ 50 μb/nucleon each at $\sqrt{s} \sim$ 27 GeV (SPS/FNAL) and $\sim$ 250 μb and $\sim$ 500 μb respectively at $\sqrt{s} \sim$ 60 GeV (ISR) an approximate estimate of $\sigma\Lambda_c^+$ and $\sigma D^{\pm}$ at $\sqrt{s} \sim$ 40 GeV (Tevatron) is $\sim$ 150 μb/nucleon and $\sim$ 250 μb/nucleon respectively. Based on these estimates we now calculate the signal that we will observe in our experiment.

2.2 Scanning criteria for charged charm

A charged charm particle will decay into an odd number of charged particle (1, 3, 5, ...). Since the 1 prong decays are difficult to disentangle from quasi-elastic scattering, as in our earlier work[6] we will be scanning for $\geqslant$ 3 prong decays of shower tracks coming from the primary p-nucleus interactions. The region around a primary interaction may be divided into two parts: one region corresponding to a narrow forward cone in which the secondaries are more collimated and each can be followed upto a relatively large distance within the same emulsion pellicle; the other, outside this forward cone in which the inter-angular separation between secondaries is quite large and since they make large angles with respect to the beam direction their length within the pellicle is quite small. We propose to carry out charm search in these two regions using different scanning criteria.

In the forward region, which we define by $\theta_{prod} < 70$ mrad (for 1 TeV interactions the lab forward cone corresponds to $\theta_{prod} < 44$ mrad), all the shower tracks will be followed upto a maximum length of 2 mm or till they decay or interact or leave the emulsion pellicle.

In the region $\theta_{prod} > 70$ mrad all shower tracks will be followed upto a maximum length of 500 μm.

One will note down any secondary activity associated with a shower track (decay, interactions, etc.).

2.3 Selection Criteria

In the forward region the density of the shower tracks near the primary vertex is so high that it is difficult to distinguish a decay vertex clearly. In our 400 GeV work we had put a minimum length cut-off for accepting a secondary activity at 100 μm from the primary vertex. At 1 TeV we propose to put a cut-off at 200 μm since the average shower multiplicity will be higher at this energy.

In the outer region ($\theta_{prod} > 70$ mrad) we propose to put a minimum length cut-off of 50 μm. This is to remove those ambiguous secondary events in which it cannot be distinguished whether the so-called decay tracks are coming from the secondary or the primary vertex. Such an ambiguity arises when the decay angles are small and the length available is not sufficient to use the grain count method.

Using the above selection criteria and the values of σ_{Λ_c} and $\sigma_{D^\pm}$ mentioned in Sec.2.1 the number of all charged charm decays we expect to see is $\sim$32 in a sample of 6000 stars which we plan to scrutinize in about 1 year's time (see Appendix A for details). In case the values of σ_{Λ_c} and $\sigma_{D^\pm}$ are lower than given in Sec.2.1, taking $\sigma_{\Lambda_c} \sim 100$ μb/nucleon and $\sigma_{D^\pm} \sim 150$ μb/nucleon, the total number of charged charm events which we will see is $\sim$20.

3. Background for charged charm

Processes which simulate a three prong vertex (all prongs being shower tracks) will constitute a background to a charm particle decay into three prongs (we neglect charm decay into 5 prongs because the branching ratio is very small). These processes are -

i) a secondary interaction with $N_h=0$, $n_s=3$.

ii) γ overlap on a shower track (owing to finite resolution a γ materializing into an e^+e^- pair very near a shower track will look like a 3-prong event).

iii) trident and pseudo-trident events due to electrons coming from Dalitz decays of π^0's produced in the primary interactions and π^0 decays and subsequent γ materialization very close to the primary vertex.

As shown in our work at 400 GeV/c [6] the backgrounds due to ii) and iii) can be eliminated making use of the fact that the θ_{op} (maximum angle between decay tracks) distributions for these processes are very different from that expected from charm decay.

The procedure used is :

a) Since the θ_{op} distribution for γ overlap and trident/ pseudo-trident production is very sharply peaked at zero, eliminate all candidates with $\theta_{op} < 10$ mrad. Carrying out Monte Carlo calculations we find that even at 1 TeV, the percentage of charm events so lost is $\lesssim$ 5% and can be corrected for,

b) carrying out scattering measurements on the decay tracks of the remaining 3-prong events. The events due to γ overlap, trident/pseudo-trident production will have either the e^+ or the e^- of momentum $\lesssim$ 150 MeV/c. Thus at least one of the electrons can be identified quite easily using momentum vs ionization information.

This leaves us with only one source of background: due to secondary interactions with $N_h = 0$, $n_s = 3$. For 6000 primary interactions we estimate this background to be $\sim$ 8 events for our scanning criteria (see Appendix B).

Thus, even under the assumption of a conservative charm production cross-section, the signal to background ratio will be 2.5:1. For a more reasonable cross section for charm production this ratio will be $\sim$ 4:1 (see Sec.2.1.2).

4. Time Schedule

We would like to engage 10 scanners for our Charm Search Work. Based on our earlier experience in 400 GeV/c charm work, we know that

$\sim$ 2.5 stars can be fully scrutinized by one scanner in one day (this includes scanning, checking of beam track, sketching and following of the secondary tracks to the desired lengths). Having ten scanners it will be possible to fully scrutinise 25 stars / day. Taking 20 working days a month, a total sample of 6000 stars can be scrutinized in about one year time. Measurements by physicists on interesting events shall be done side by side.

5. Fermilab facilities requested

The machining and alignment of the emulsion stack will have to be done at the experiment site. The flux of the proton beam should be reasonably uniform over an area of $\sim$ 4 X 8 cm^2. If it is possible we would like to request that the stack may be processed at Fermilab itself to prevent cosmic ray background during air transit.

APPENDIX I

Calculation for the expected number of charm decays

In order to estimate the total number of charged charm decays (Λ_c^+, and $D^\pm$) we interpolate the cross sections between SPS/FNAL energies and ISR energies. As mentioned in Sect. 2.1. we expect $\sigma_{\Lambda_c} \sim 150\ \mu b$ / nucleon and $\sigma_{D^\pm} \sim 250\ \mu b$ / nucleon. Assuming a linear A dependence of the charm cross-section, the number of N_{charm} (→ 3 prong) is given by

$$N_{charm}\ (\to 3\ prong) = \sigma_{charm} \times Br(\to 3\ prong) \times \text{No.of stars} \times A/\sigma_A$$

where σ_A is the inelastic cross-section on a nucleus of mass A.

For emulsion $\langle A \rangle = 29$ and $\sigma_A = 383$ mb, thus if σ_{charm} is in μb / nucleon,

$$N_{charm}\ (\to 3\ prong) = \sigma_{charm} \times Br\ (\to 3\ prong) \times \text{No.of stars} \times 7.572 \times 10^{-5}$$

With $\sigma_{\Lambda_c} = 150\ \mu b$, Br (→ 3 prong) = 0.6 and total number of stars = 6000, one gets $N_{\Lambda_c^+}$ (→ 3 prong) = 41.
With $\sigma_{D^\pm} = 250\ \mu b$ and Br (→ 3 prong) = 0.6 for the same number of stars, one expects $N_{D^\pm}$ (→ 3 prong) = 68.

Out of these 41 Λ_c^+ and 68 $D^\pm$ charm decays, the number that will decay in our scanning region depends upon the dynamics invovled in the production process of these particles and their life times. It is shown at ISR energies that $d\sigma/dp_T^2 \propto e^{-bp_T}$ for both Λ_c^+ and

$D^{\pm}$ with b ≈2 in both the cases. For x distribution at ISR energies, one finds that $d\sigma/dx$ for $D^{\pm}$ is $\propto (1-x)^3$ and that for Λ_c^+ is flat similar to Λ^o. In order to calculate the Λ_c^+ and $D^{\pm}$ charm decays in our scanning region we use the best fit for x distribution of Λ^o at 200–400 GeV and that for D as $(1-|x|)^3$. Thus we take the invariant cross section for Λ_c^+ decays as

$$E \frac{d^3\sigma}{dxdp_T^2} \propto (1-|x|)\,[0.192+10x^2\, e^{(-2.648x^2)}]\, e^{-2p_T}$$

and that for D

$$E \frac{d^3\sigma}{dxdp_T^2} \propto (1-|x|)^3\, e^{-2p_T}$$

Taking life time of Λ_c^+ decays between $1.0 - 2.0 \times 10^{-13}$ sec and of $D^{\pm}$ as 9.3×10^{-13} sec. the expected number of $\Lambda_c^{\pm}$ and $D^{\pm}$ decays are given in the table below both for the forward and backward regions.

Table 1: Λ_c^+ and D decays in forward region of $\theta<70$ mrad

$L_{min} - L_{max}$ followed (μm)	Λ_c^+ seen	$D^{\pm}$ seen	Total
200 - 2000	10.5	14	24.5
200 - 3000	13.0	20	33.0
200 - 4000	14.0	24	38.0

<u>Table 2</u> Λ_c^+ and D decays in the backward region of $\theta > 70$ mrad.

$L_{min} - L_{max}$ (μm)	Λ_c^+ seen.	$D^{\pm}$ seen.	Total
50 — 300	5.3	negligible	5.3
50 - 400	6.2		6.2
50 - 500	7.0		7.0

As the secondary interaction background increases almost linearly with increasing track length, the best signal to background ratio in the forward region is obtained for a maximum track length followed = 2000 μm. In the backward region since the track length followed is very small, the total secondary interaction background estimated is < 1-event (See appendix II). In summary we search in the forward region (< 70 mrad) from 200 μm - 2000 μm and expect 25 charged charm decays. The secondary interaction background estimated is 7.2. In the backward region we search from 50 μm - 500 μm and expect 7 Λ_c^+ decays ($D^{\pm}$ decays are negligible) and 0.9 secondary interaction's background. In all one expects 32 charm decays and 8 secondary interaction's background. Taking, however, more conservative values for Λ_c^+ and $D^{\pm}$ cross section's of 100 μb and 150 μb respectively one expects a total of 20 charm decays in the same scanning regions.

APPENDIX II

Extrapolating from the information available at 400 GeV and below one expects a multiplicity of $\approx$ 20 shower tracks in p-emulsion interactions at 1000 GeV. Assuming that the major contribution to the shower multiplicity (pion production) comes basically from central region, one expects $\sim$ 11.5 shower tracks in the forward region of $\lessdot$ 70 mrad and $\sim$ 8.5 shower tracks in the outer cone.

The total track length followed in the forward region (where one will be following to a maximum of 2 mm and with an L_{min} cut of 200 μm) for 6000 stars.

$$L_F = (0.2 - 0.02) \times 11.5 \times 6000 \text{ cm} = 12420 \text{ cm}.$$

Taking $\lambda_{\pi\text{-em}} = 45$ cm

the total number of secondary interactions

$$= \frac{12420}{45} = 276$$

The energy of shower tracks in the forward region of < 70 mrad will be between 20-40 GeV.

The probability of having $N_h = 0$, $n_s = 3$ stars at 17 GeV is 1.8% [10] and that at 45 GeV is 3.4% [11]. Taking the average of the two values one gets $\sim$ 2.6%.

Thus using this probability of 2.6% for N_n=0, n_s=3 stars one gets

$$276 \times \frac{2.6}{100} = 7.2 \qquad N_h = 0,\ n_s = 3 \text{ stars}$$

In backward region of $>$ 70 mrad the average energy of shower tracks will be $\sim$ 5-10 GeV. We will take the probability of N_h=0, n_s=3, stars as 1.8%.

The track length followed in the backward region

$$L_B = (.05 - 0.005)\text{ cm. X } 8.5 \text{ X } 6000 \text{ cm} = 2295 \text{ cm}$$

With $\lambda_{\pi-em}$ = 45 cm

total number of secondary interactions

$$= \frac{2295}{45} = 51 \text{ stars}$$

No. of stars with $N_h = 0$, $n_s = 3 = 51 \text{ X } \frac{1.8}{100} = 0.9$ stars

Thus total number of secondary interaction background with N_h=0, n_s = 3 in 6000 stars

= 7.2 + 0.9 = 8 stars.

References

1 N,N. Nikolev, A.Ta Ostapchuk and V.R. Zoller
CERN Preprint Th. 2561 (1978)
F.K. Aliev et al., Lett. Nuo. Cim. 23 (1978) 212.
A. Bialas, W. Czyz and W. Furmanski, Acta Phys. Pol. 82 (1977) 88.
A. Bialas, FERMILAB Conf. 79/35 Thy (1979).

2 S.J. Broadsky, SLAC-PUB-2395 (1979)

3 B. Andersson, I. Otterlund and E. Steulund
LUNFD6/ (NFFK-7002) 1-8 (1979)
I. Otterlund, LUNFD6 /(NFFK-7004) 1-43 (1979)

4 A. Zichichi, Rapporteur talk, Int. Conf. on High Energy Physics, LISBON, July (1981), CERN-EP/82-20.
J. Irion et al., Phys. Lett. 99B (1980), 495.

5 BEBC Collaboration, P. Fritze et al., Phys. Lett. 96B (1980) 435
CDHS Collaboration, quoted by D. Treille in Symp. on Lepton and Photon interactions at High Energies, Bonn, Aus (1981).
CHARM Collaboration, M. Jonker et al., Phys. Lett. 96B (1980) 435.

6 A. Bodek et al., Rochester University report, COO-3065-307 (1981).
R.C. Ball et al., Michigan University report UM-HE-81-48 (1981).

6 BCDJ Collaboration, T. Aziz et al., Nucl. Phys. B199 (1982) 424.
ABCCMR Collaboration, quoted by D. Trielle. (see 5).

7 CDHS Collaboration, H. Abramowiez et al., Z. Phys. C. 13 (1982) 179.

8 T. Aziz and A. Gurtu, TIFR-BC-82-5.

9 R.T. Edwards et al. Phys. Rev. D18 (1978) 76.

10 S.A. Azimov et al. Sov. J. Nucl. Phys. 2 (1966) 747.

11 E.V. Anzon et al. Phys. Lett. 31B (1970) 241.